U S D A FOREST SERVICE
RESEARCH NOTE RM-180

FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

BRISTLECONE PINE-- Its Phenology, Cone Maturity, and Seed Production in the San Francisco Peaks, Arizona

Gilbert H. Schubert
and W. J. Rietveld[1]

Vegetative buds start swelling early in June, with bud-bursting and active elongation in mid-June. Male flowers are mature and release pollen by late July. Seed viability is strongly correlated with specific gravity (drying, maturity) of cones on the tree. Cones are uniform in shape, but vary greatly in size. Number of sound seeds per cone is strongly correlated with total seeds, but only weakly correlated with cone specific gravity and length.

KEY WORDS: *Pinus aristata*, forest seed production, cone collecting.

Bristlecone pine (Pinus aristata Engelm.), a subalpine species, occurs in widely scattered areas in the mountains of eastern California, Nevada, Utah, Colorado, northern Arizona, and northern New Mexico (Critchfield and Little 1966). Bristlecone pine normally attains a height of only 15 to 30 feet and a diameter of 12 to 18 inches. The tree, noted for its long life (Ferguson 1968, Fritts 1969, Schulman 1958), is intolerant of competition and is replaced by the more tolerant spruces (Picea spp.), Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), and true firs (Abies spp.). Bristlecone pine is valuable mainly for its use in dating events, its natural esthetics on high mountain slopes, its soils building and stabilization in inhospitable environments, and its ecological significance to animals and other plant associates.

In several pines, specific gravity of maturing cones has proved to be a reliable index of the ripeness of the enclosed seeds. The specific gravity required for acceptable germination has been determined for sugar pine (Pinus lambertiana Dougl.) (Fowells 1949), ponderosa pine (P. ponderosa Laws.) (Maki 1940), and Jeffrey pine (P. jeffreyi Grev. & Balf.) (Schubert 1955). Present literature provides ample references to dendrochronology, but very little is available on the seeding habits of bristlecone pine. Phenological observations, cone maturity indicators, and seed yields for bristlecone pine are presented here.

Study Area and Methods

Flowers and cones were collected from a young stand of bristlecone pines along the west edge of the San Francisco Peaks Natural Area. This stand, at an elevation of 9,500 to 9,680 feet, is located about 11 miles north of Flagstaff, Arizona (fig. 1).

[1] *Principal Silviculturist and Associate Plant Physiologist, respectively, located at Flagstaff in cooperation with Northern Arizona University; central headquarters maintained at Fort Collins in cooperation with Colorado State University.*

Figure 1.--The study area--a thrifty stand of young bristlecone pine at 9,500 to 9,680 feet elevation on the west slope of the San Francisco Peaks in northern Arizona.

The site is characterized by a cold-moist climate (table 1). Mean monthly temperatures during a 3-year period ranged from 23° F. in January to 57° F. in June. During the winter months, the temperature dropped to -4° F., about 15° warmer than at Fort Valley Experimental Forest for the same time period. The maximum temperature seldom exceeded 90° F., with a mean maximum of about 68° F. in June. Precipitation averaged about 35 inches—12 inches more than at the base of the mountain.

The study area consists of a nearly pure stand of young bristlecone pines. This natural stand, which started about 50 years ago on an open grass site, is increasing in area. Just above the plot, older bristlecone pines are associated with quaking aspen (Populus tremuloides Michx.), Engelmann spruce (Picea engelmannii Parry), white and corkbark firs (Abies concolor (Gord. & Glend.) Lindl. and A. lasiocarpa var. arizonica (Merriam) Lemm.), and Douglas-fir.

Four cone collections of 20 to 30 cones each were made in the young stand during the fall of 1968, and another of 460 cones in 1969. The 1968 collections were spread over a 9-day period starting on September 24. Cones from each collection were measured shortly after picking to obtain data on cone length, width, weight, and volume.

Individual cones were then placed in small paper bags and allowed to open in a growth chamber set at an alternating temperature of 70° to 90° F. Number of days to open and total number of seeds was determined for each cone. The seeds were then stored at 0° F. until September 3, 1969, when a germination test was started. At the conclusion of the germination test, all ungerminated seeds were cut open to determine soundness.

Cones were collected in 1969 to obtain data on cones and seeds per bushel and per 100 pounds, specific gravity of open cones, and moisture content of extracted seed. Cones that failed to open within 4 days at a temperature of 70° to 90°F. were discarded as being of questionable maturity.

In 1969, flower development was observed from June until ovulate strobili received pollen.

Table 1.--Mean monthly temperature and precipitation at an elevation of 9,400 feet on west slope of the San Francisco Peaks, Arizona, 1917-19

Month	Temperature				Average precipitation
	Maximum	Mean	Minimum	Lowest	
	- - - - °Fahrenheit - - - -				Inches
January	29.5	22.9	16.5	-4	1.85
February	30.0	23.7	17.4	3	3.13
March	35.0	27.3	19.6	12	3.89
April	44.6	36.0	27.5	16	2.24
May	50.9	41.4	31.9	21	1.44
June	68.2	57.2	46.2	37	.66
July	64.3	56.2	47.1	41	8.73
August	64.1	55.5	46.8	40	2.79
September	59.0	50.9	42.8	32	2.39
October	49.2	41.6	34.0	19	2.16
November	38.5	31.9	25.8	6	3.30
December	34.5	28.8	23.9	-4	2.33
Annual	47.3	39.4	31.6	-4	34.91

Results and Discussion

Vegetative bud growth began in early June 1969; bud opening and active elongation began on June 15. Pearson (1931) indicated old trees opened buds from June 20-30 (table 2), about 5 to 15 days later than we observed for young trees. Fritts (1969) reported young bristlecone pines in the White Mountains of California initiated growth on June 25 in 1962, June 14 in 1963, and June 24 in 1964. Fritts also found that bud growth began 4 to 17 days later on old trees than on young trees. These differences are of the same magnitude as those observed in the San Francisco Peaks.

The dark purple female and orange to red colored male flower buds were fully developed by July 22, 1969. Pollen shedding started about the same time female flower buds opened, and pollen dissemination lasted approximately 5 days.

A few cones were opening on September 27, 1969, with greater numbers by October 2. Most of the cones were open by October 10. Pearson (1931) reported that seeds mature from September 20 to October 10. Our earliest cone collections on September 24 yielded some mature seeds.

Cone specific gravity dropped most rapidly between September 24-25 and September 27. During this 4-day period, average specific gravity of the cones dropped from 0.83 to 0.68. By October 2, the average specific gravity was 0.65. Cones started to open when the specific gravity dropped to 0.62 and were completely open at 0.57. Since cones started to open when the specific gravity reached 0.62, cone collections after October 5 in 1968 would have resulted in low seed yields. Cone opening started at the same specific gravity as that determined for sugar and ponderosa pine in California (Schubert 1955).

Table 2.--Phenologic data for bristlecone pine in the San Francisco Peaks area, 1918-23 (Pearson 1931) and 1969

Plant activity	1918-23	1969
Vegetative buds swelling	June 1-20	June 1
Vegetative buds elongating or opening	June 20-30	June 15
Shoots making rapid growth	July 1-30	--
Male buds appearing	July 1-10	--
Female and male buds mature	--	July 22
Pollen falling	July 20-Aug 20	July 22-27
Cones full grown	Sept 10-20	--
Seeds mature	Sept 20-Oct 10	Sept 24-Oct 2
Cones opening	--	Sept 27-Oct 10
Leaves falling	Oct 1-30	--
Period of active growth	June 20-Sept 20	--

Cones with the lowest specific gravity opened fastest. Those collected on September 24-25 with an average specific gravity of 0.83 required over 4 days to open compared to only 2 days for those collected on September 27 and October 2 when specific gravity averaged between 0.65 and 0.68. The linear regression of specific gravity times days to open had a correlation coefficient (r) of 0.87 (table 3). Cones with a specific gravity over 0.92 failed to open within 10 days in the growth chamber.

Bristlecone pine cones varied greatly in size (table 4). The sample of 74 cones averaged about 7 centimeters in length and nearly 3 centimeters in width. Cone shape was consistent for all sizes, as indicated by the correlation coefficient (r) of 0.96 for the linear regression of length times width (table 3). The cones weighed about 27 grams each or about 27 pounds per bushel. Nearly 450 of these small cones were required to fill a bushel basket (table 5). A pound bag held almost 17 cones. The collections made in 1969 averaged about 40 seeds per cone or 19,800 seeds per bushel. A 100-pound bag held over 1,600 cones, with an average yield of 73,100 seeds. A bushel of cones yielded 452 to 464 grams of cleaned seed. Moisture content of extracted seeds averaged 5.6 percent on an ovendry-weight basis. These estimates were all based on bulk lots of cones collected in 1969.

Table 3.--Statistics for several linear regression relationships for bristlecone pine cones and seeds from the San Francisco Peaks in Arizona

Linear regression	$\bar{X}$	$\bar{Y}$	SD X	SD Y	Intercept	Slope	r	r^2
Cone length × cone width (mm)	7.3	2.9	1.2	0.4	0.757	0.297	0.96	0.91
Specific gravity × days for cone to open	71.3	2.8	9.2	1.7	-8.454	.157	.87	.76
Specific gravity × germination	71.3	92.6	9.2	8.3	151.609	-.828	-.92	.85
Specific gravity × full seeds	71.3	36.2	9.2	22.4	-36.658	1.021	.42	.18
Cone length × total seeds	7.3	44.2	1.2	24.0	13.649	4.202	.21	.04
Cone length × full seeds	7.3	36.2	1.2	22.4	5.859	4.164	.22	.05
Total seeds × full seeds	44.2	36.2	24.0	22.4	-4.429	.918	.98	.96

Table 4.--Variation in size of bristlecone pine cones in the San Francisco Peaks of Arizona

Variation	One cone							Bushel of cones
	Length		Width		Weight		Volume	
	Cm.	In.	Cm.	In.	Grams	Ounces	Cubic centimeters	Pounds
High	10.3	4.1	3.8	1.5	53	1.87	74	27.8
Low	5.1	2.0	2.2	.9	14	.49	22	26.4
Average	7.3	2.9	2.9	1.1	27	.95	40	27.1

Table 5.--Variation in cone and seed yield for bristlecone pine in the San Francisco Peaks of Arizona, 1969

Product and variation	Quantity of cones and seeds in relation to--					
	Seed weight			Cone weight		
	Gram	Ounce	Pound	Pound	Bushel	100-pound bag
	- - - - - - - - - - - - - - - - Number - - - - - - - - - - - - - - - -					
Cones--						
High	1.03	29.2	468	17.0	460	1,697
Low	.93	26.3	421	16.1	436	1,609
Average	.98	27.7	443	16.5	448	1,653
Seeds--						
High	42.1	1,194	19,100	751	20,400	75,100
Low	38.7	1,097	17,500	722	19,300	72,200
Average	40.0	1,134	18,100	731	19,800	73,100

Seed yields from cones collected in 1968 were similar to those collected in 1969 (table 6). An average cone had 44 seeds, of which 8 were empty. The most seeds removed from a single cone was 105; the least was 10. The cone with the most seeds also had the greatest number of sound seeds—93. Based on these estimates, one could expect about 16,000 good seeds per bushel of cones or 60,000 per 100-pound bag.

We found a very strong correlation between total seeds and full seeds per cone, as indicated by the correlation coefficient of 0.98 (table 3). We found very little correlation, however, between number of sound seeds and either specific gravity or cone length. Therefore, even small cones can be expected to have good seed yields.

Specific gravity—an index of cone dryness and maturity—did account for 91 percent of the variability in seed germination, however (table 3, fig. 2). Cones with a specific gravity of 0.75 or less when collected had the most viable seeds—over 90 percent of their sound seeds germinated. Furthermore, this mature seed was the first to germinate. Most of this fast germinating seed came from cone collections made on September 27 and October 2 (fig. 3).

Bristlecone pine seeds showed no evidence of dormancy (fig. 3). About 75 percent of the seeds germinated within 8 days. Seeds from the last two collections germinated faster than those from the first collection. No stratification or other seed treatments were tested to determine if germination could have been speeded up. Generally, stratification has been found helpful for most conifers in the "white-pine" group.

Table 6.--Variation in number of full and empty seeds for bristlecone pine in the San Francisco Peaks of Arizona, 1968

Seed quality class	Quantity of cones		
	One	Bushel	100 pounds
	- - - Number - - -		
Full--			
High	93	16,640	61,400
Low	7	15,770	58,210
Average	36	16,210	59,810
Empty--			
High	18	3,710	13,680
Low	0	3,510	12,970
Average	8	3,610	13,320
Total--			
High	105	20,350	75,080
Low	10	19,290	71,180
Average	44	19,820	73,130

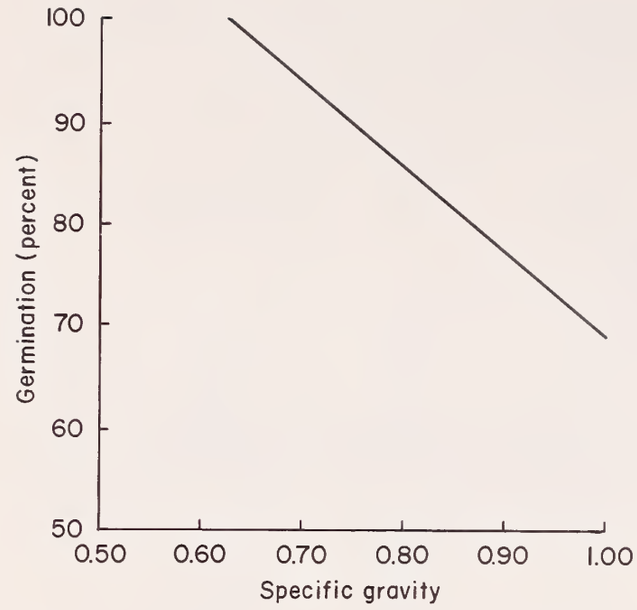

Figure 2.--Cone specific gravity as an index to seed germination for bristlecone pine from the San Francisco Peaks in Arizona.

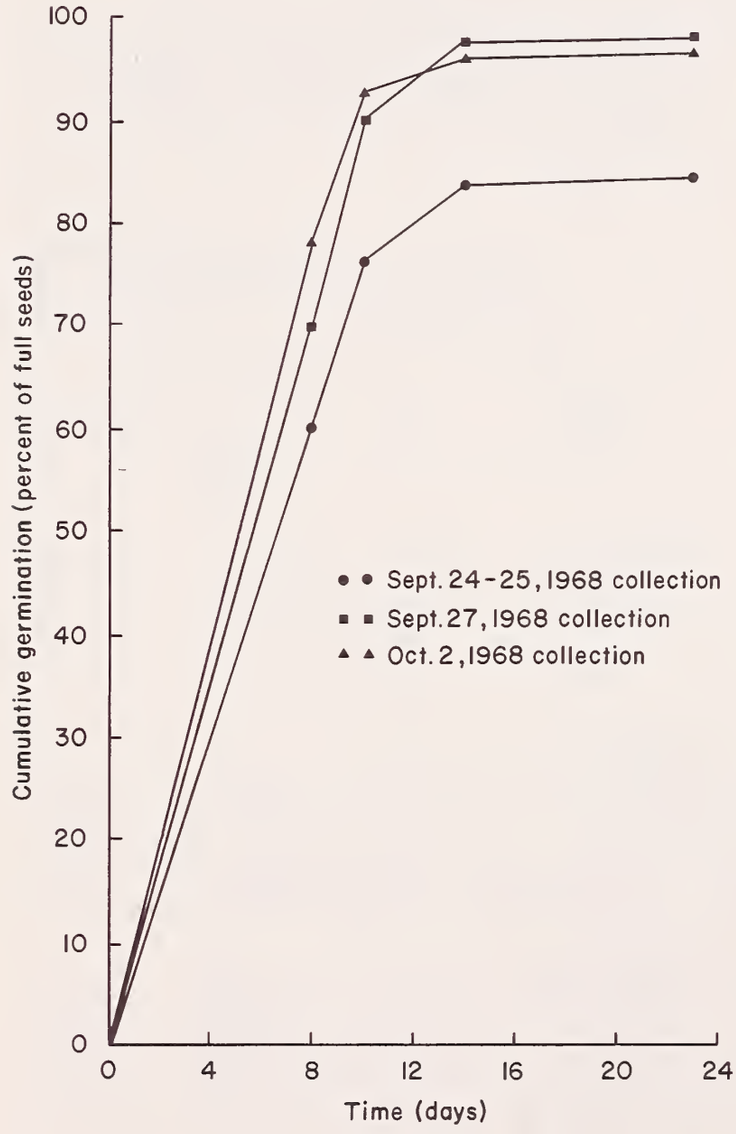

Figure 3.--Cumulative seed germination by cone collection dates for bristlecone pine from the San Francisco Peaks in Arizona.

Summary

This information should help anyone time his visit to a stand of bristlecone pines with the occurrence of a particular growth event. Basic cone and seed data are also presented.

The principal results of the study are:

1. Vegetative buds of bristlecone pine started swelling in early June, with bud-bursting and active elongation in mid-June. Flower buds matured around July 22, and pollen was released for about 5 days. Seeds matured from September 24 to October 2, and were released from September 27 to October 10.
2. Seed viability is strongly correlated with cone specific gravity. Cones yielded the most viable seeds if they were collected after their specific gravity had dropped to 0.75 or less. Most cones began to open when their specific gravity reached 0.62, and were completely open at 0.57. For these reasons, cones should be collected when their specific gravity falls below 0.75.
3. Bristlecone pine cones are uniform in shape, but vary greatly in size, with an average length of about 7 centimeters and width of 3 centimeters. About 17 cones are required to make a pound, and about 27 pounds of cones fill a bushel basket. The number of seeds per cone ranges from 10 to 105, but averages 40. A bushel of cones yields about 1 pound of seed (452-464 grams). There are about 16,000 sound seeds per bushel of cones.
4. The number of sound seeds per cone is strongly correlated with total seeds. There is little correlation, however, between number of sound seeds and either specific gravity or cone length. Therefore, it appears worthwhile to collect small cones in addition to large ones.
5. Although no particular stratification treatments were tested, there did not appear to be any requirement for such a treatment.

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Pearson—
bristlecone germinated promptly in tests begun Feb 19,
Apr 1, kept in unheated greenhouse
pollen shedding 7/20 - 8/20
1917-1919

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